Met.O.854
METEOROLOGICAL OFFICE

the meteorological magazine

METEOROLOGICAL OFFICE
16 MAR 1972
MAFF BRISTOL

MARCH 1972 No 1196 Vol 101
Her Majesty's Stationery Office

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By R. Dixon, B.Sc. and E. A. Spackman, M.Sc.

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METEOROLOGICAL OFFICE Met.O.854

THE METEOROLOGICAL MAGAZINE

Vol. 101, No. 1196, March, 1972

551.509.331:551.557.33:551.590.3

SPRING AND AUTUMN REVERSALS OF STRATOSPHERIC WINDS OVER SCOTLAND

By R. A. EBDON

Summary. Wind data for 30 mb over Scotland have been used to illustrate the behaviour of the spring change from westerly to easterly zonal components for the years 1958–71 and for the autumn change from easterly to westerly for the years 1958–70.

Possible connections between the time of the spring reversal and both the weather of the following summer and the phase of the quasi-biennial oscillation in equatorial stratospheric winds are discussed.

It is suggested that dust from the Jan Mayen volcanic eruption in September 1970 may have influenced high-latitude stratospheric events in 1971.

Introduction. In 1902 when Teisserenc de Bort 'discovered' the stratosphere and for the following 50 years or so, meteorologists generally were of the opinion that conditions above the tropopause were comparatively calm and rather uninteresting. Then in 1952 the late Professor Scherhag reported the phenomenal 'Berlin warming'[1] and from that time on much more interest has been focused on events which take place above the tropopause. The pursuit of this interest has been made possible by the steady improvement in the number of radiosonde ascents reaching levels above 50 mb (approximately 20 km) and it has been stimulated by the increasing need to improve our understanding of stratospheric events. The need for this knowledge arises in two ways: (a) to meet the demands of those engaged in theoretical studies of the general circulation and (b) to meet the demands of those concerned with the operation of aircraft at mid-stratospheric levels.

In recent years two particular stratospheric phenomena have featured very prominently in the literature, namely, the 'quasi-biennial oscillation', which is most marked in low latitudes and the 'final warming', which is restricted to higher latitudes. Both of these phenomena are referred to in a paper entitled 'The structure and dynamics of the stratosphere' by Murgatroyd.[2]

The main purpose of this note is to draw attention to a particular aspect of the final warming. It is now a well-established fact that in winter the high-latitude stratosphere is dominated by two features — a cold circumpolar vortex with a strong westerly circulation, and a warm high centred over the Aleutian/Kamchatka area. In summer there is a complete reversal of the flow and the dominant feature in the stratosphere is a warm high centred near the North Pole, with a very light easterly drift over high latitudes. The

time at which this warming of the stratosphere and reversal of the circulation takes place and the way in which it happens can and does vary quite considerably from year to year.

The spring reversal. There are many ways of examining the breakdown of the winter polar stratospheric vortex and a variety of ways of defining the time at which the event happens. One simple parameter which can be used (although no claim is made that it is better than any other) is the pentad, i.e. 5-day, mean zonal wind component at 30 mb (approximately 24 km) over Scotland. The averages of the pentad mean values for January to October for the period 1958–70 are shown in Figure 1. The winter westerlies which

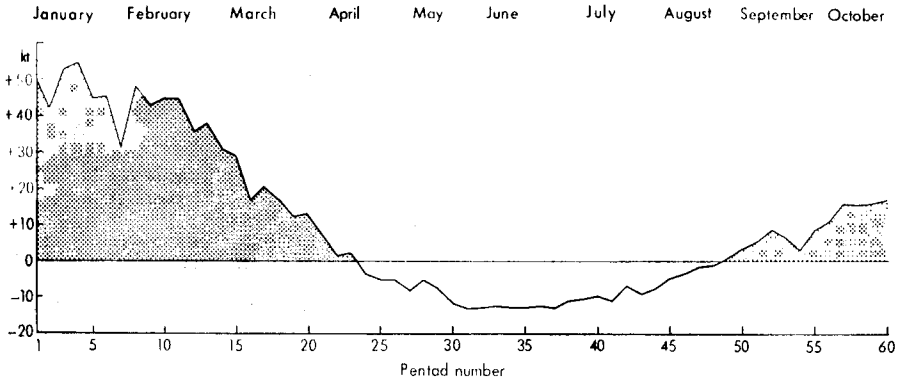


FIGURE 1—PENTAD AVERAGE ZONAL WIND COMPONENTS AT 30 mb OVER SCOTLAND FOR JANUARY–OCTOBER (1958–70)

Components towards the east are positive and stippled. Data for Leuchars/Shanwell combined with Stornoway.

are stronger than 40 kt for most of January and February decrease in the spring and change to light easterly towards the end of April. The pentad average zonal component remains about 10 kt easterly throughout the summer and changes back to westerly again by late August or early September. However, as can be seen in Figure 2, the time of the change-over to easterlies does vary considerably from one year to another.

It is not easy to devise a completely satisfactory definition of the date of change, particularly when dealing with the data from only one station. Indicators which can be used are :

(a) the last pentad mean zonal wind component > 5 kt westerly,
(b) the first pentad mean zonal wind component > 5 kt easterly,
(c) the first easterly pentad mean zonal wind component, and
(d) the first pentad mean zonal wind component > 5 kt easterly, after which the pentad mean remains either easterly or less than 5 kt westerly.

Clearly there are some years when all of these indicators suggest either an 'early' or a 'late' change-over. In such cases it is probable that other indicators using other parameters would usually — but not necessarily always — give similar indications for hemispheric events (e.g. the date when a high was first established near the North Pole or the date when 'summer' temperature values were first recorded in polar latitudes). Nevertheless

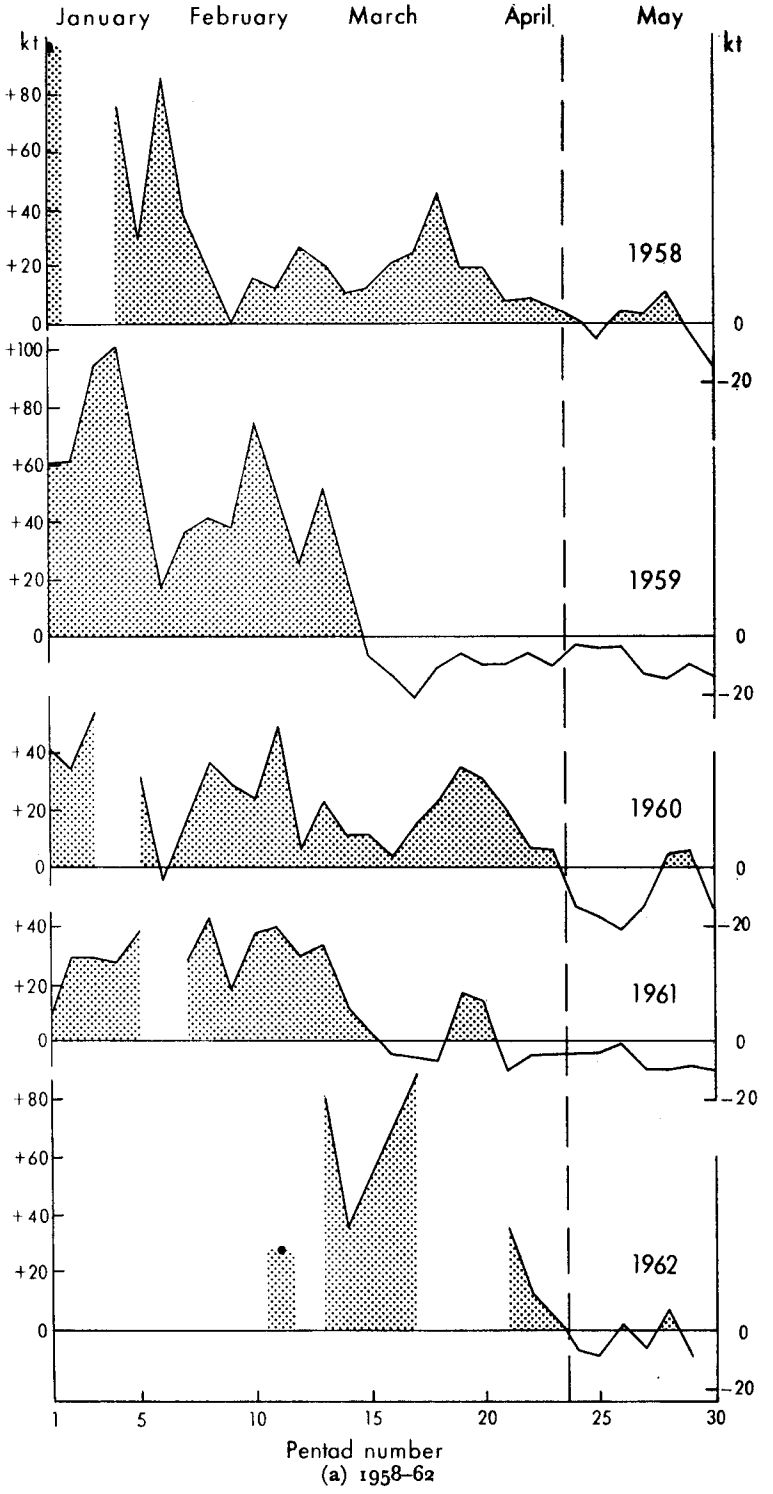
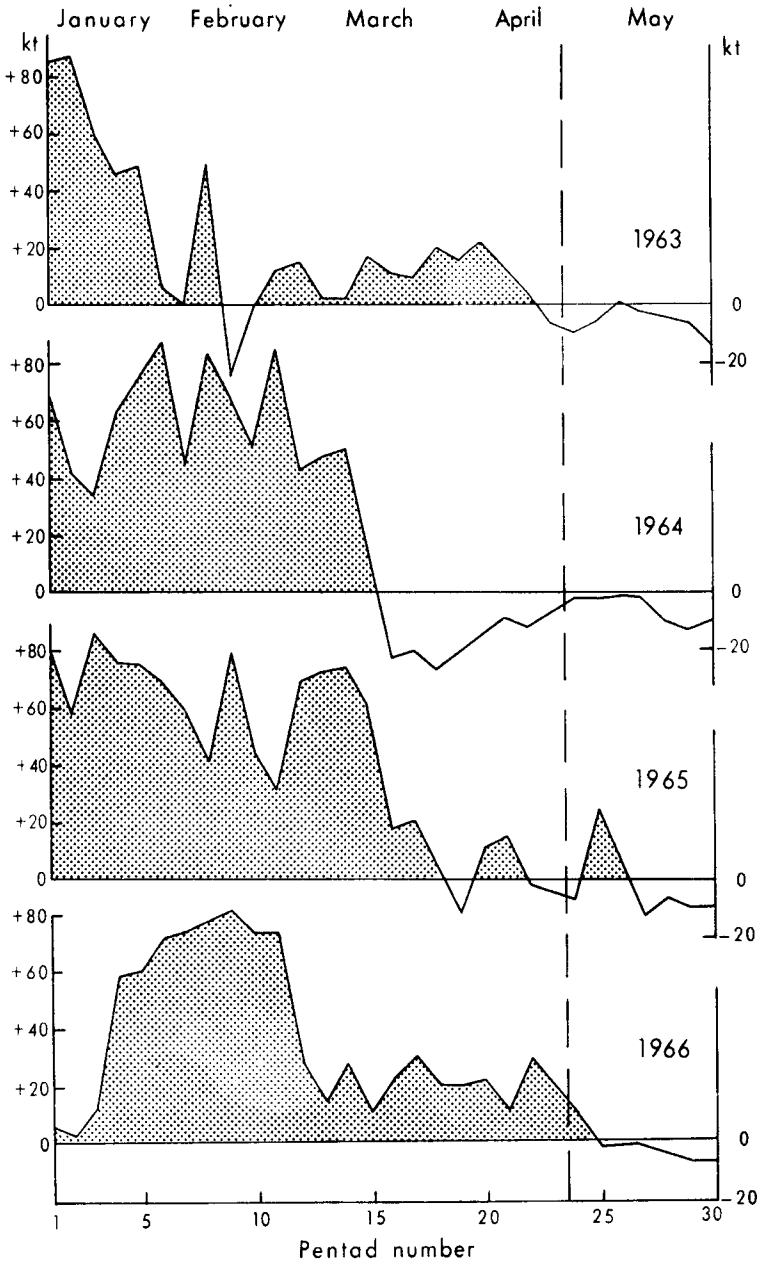


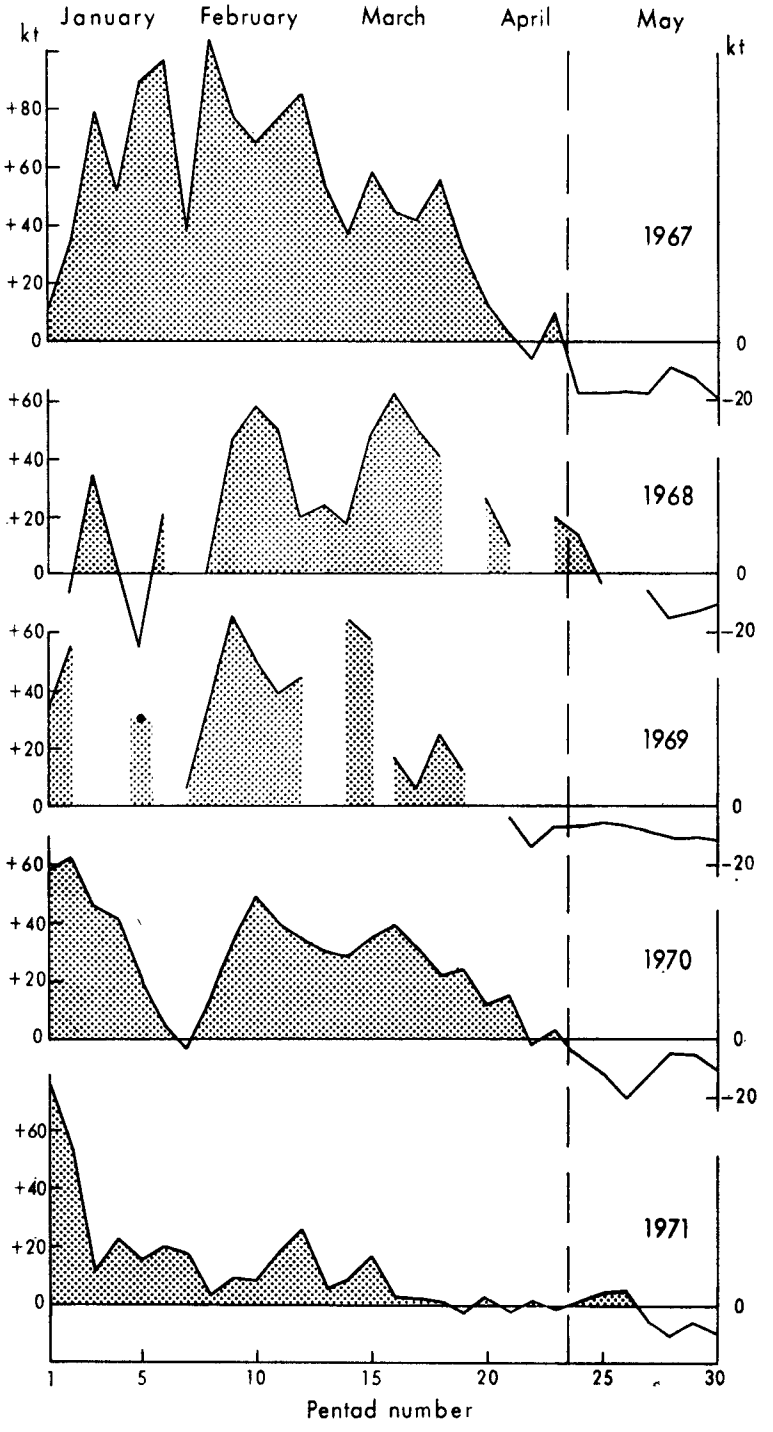
FIGURE 2—PENTAD MEAN ZONAL WIND COMPONENTS AT 30 mb OVER SCOTLAND FOR JANUARY TO MAY OF EACH OF THE YEARS 1958–71

Components towards the east are positive and stippled. The average time of the change-over to easterly is shown by the pecked line.



(b) 1963–66

FIGURE 2—*contd.*



(c) 1967–71

FIGURE 2—*contd.*

there are years when it is extremely difficult to classify the change-over as either 'early' or 'late' and these years also tend to be difficult to classify on a hemispheric scale. If the criteria listed above are applied to Figure 2 then there are years, such as 1959, 1961, 1964 and 1969, when it is seen that the easterlies are definitely established early. There are other years, such as 1958, 1960, 1962, 1966 and 1968, when the change-over can be said to be late. There is another group of years, 1963, 1965, 1967, 1970 and 1971, when it is difficult to classify the onset of the easterlies with any degree of certainty although some of these might be considered as average.

The spring reversal and possible indications of the weather of the following summer. In an earlier paper[3] it was suggested that there might be some correlation between the time of occurrence of this event in the stratosphere in spring and the weather of the following summer, as measured by Poulter's index of the summer at Kew; this index is defined as $10T + S/6 - R/5$, where, for June, July and August, T = mean temperature (°F), S = total sunshine hours, and R = total rainfall (mm). Table I shows the values of the summer index at Kew for the years 1958–70.

TABLE I—VALUE OF POULTER'S SUMMER INDEX AT KEW FOR 1958–70

	1958	1959	1960	1961	1962	1963	1964
Kew summer index	650	759	683	700	671	670	690
	1965	1966	1967	1968	1969	1970	
Kew summer index	658	670	708	647	701*	716	

* Approximate value as no north-wall screen temperatures available in June.

In the five years — 1958, 1960, 1962, 1966 and 1968 — which can be classified with reasonable certainty as a late change-over, the average summer index was 664. The four years which were quite definitely early give an average summer index at Kew of 712. As has been stressed already, it is quite difficult in some years to classify the change-over but Table II was prepared using the criteria in (d) on page 66.

TABLE II—RELATIONSHIP BETWEEN SPRING REVERSAL OF 30-mb WINDS OVER SCOTLAND AND INDEX OF THE FOLLOWING SUMMER AT KEW

Time of spring reversal	Kew summer index ≥690	689 – 671	≤670
Late	0	2 (60) (62)	4 (58) (66) (65) (68)
Average, pentads 23/24	2 (67) (70)	0	1 (63)
Early	4 (59) (64) (61) (69)	0	0

Years are indicated in brackets.

The four years with an early change-over to easterlies at 30 mb have all been followed by above-average summers. On the other hand, a late change-over has never been followed by an outstandingly good summer and, in fact, all six of the years in that category have a summer index at Kew below the 13-year average of 686.

Charts of the departure from average of the optimum summer index for a large number of stations in the United Kingdom, prepared by N. E. Davis, show that in years with an early final stratospheric warming the summer

is better than average over a large part of the country (with the exception of north-west Scotland). The improvement is greatest in an area which includes east Devon, east Somerset, south Wiltshire, Dorset, Hampshire and West Sussex. In years with a late final stratospheric warming the summers are below average over most of the country except north-west Scotland. The largest departures from the average occur in Norfolk, Suffolk and Essex.

Japanese workers[4] have found that the breakdown of the stratospheric vortex and the time of the final warming provides guidance for their forecasting of the summer season in Japan.

Using an index of meridionality at 10 mb in the spring stratosphere as an indicator, Ugrjumov[5] has produced maps of the mean June pressure over temperate- and high-latitudes of Eurasia for the 'early' years 1959, 1961 and 1964 and the 'late' years 1958, 1963 and 1965. These maps varied considerably and in the 'early' years the circulation was determined largely by the ridge from the Azores anticyclone whereas in the 'late' years cyclones predominated over Europe. He found that in years which were 'average' as regards the spring reversal the surface-pressure situations fell between these two patterns.

Hemispheric charts of surface pressure and their anomalies have been produced for the months of June, July, August and September, based on years when the spring change-over of 30-mb winds over Scotland was (a) early, (b) late and (c) not possible to classify with any confidence. The years used in preparing the average charts were :

(a) 1959, 1961, 1964 and 1969.
(b) 1958, 1960, 1962, 1965, 1966 and 1968.
(c) 1963, 1967 and 1970.

These charts show that, over the British Isles, there is little difference in the average pressure charts for June but in July, August and September the ridge from the Azores anticyclone is a more prominent feature, particularly over southern England and pressures are appreciably higher than in the years following a late warming. The pressure differences (mean of 'early' years – mean of 'late' years) amount to 2 or 3 mb in July, 4 mb in August and 4 mb in September. In July the maximum difference (3 mb) is centred off south-west England but in August and September the maximum (up to 4 mb) lies between approximately 50° and 55°N.

Clearly, on the basis of the few years of available data, it is not possible to form any reliable rule for obtaining a forecast of the summer index. If the evidence of the past 13 years continues then perhaps the time will come when it will be possible to infer with some confidence that the date, and perhaps the manner, of the stratospheric-wind reversal and final warming does have a bearing on the character of the following summer in some parts of the northern hemisphere. This is, of course, a purely statistical relationship and, to date, little or no work has been done on the more interesting aspect of trying to determine the underlying physical causes for such a possible relationship.

The spring reversal and possible links with the quasi-biennial oscillation. It has been suggested that the phase of the quasi-biennial oscillation in equatorial stratospheric winds has a bearing on the time of the final warming in high latitudes.[6,7] That this may be so can be seen from Table III.

TABLE III—30-mb MONTHLY MEAN ZONAL WIND COMPONENTS AT CANTON ISLAND (2°46′S 171°43′W), 1958–67, AND AT GAN (00°41′S 73°09′E) FROM 1968 ONWARDS

	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
							knots							
Jan.	+12·8	−51·9	−3·6	−6·6	+12·6	−54·1	+6·6	+1·4	−59·9	+29·4	−41·3	−3·5	−18·9	−0·8
Feb.	+11·1	−54·7	−5·6	+6·0	+14·4	−62·1	+4·1	−1·6	−42·3	+24·9	−36·5	+9·1	−27·0	+6·9
Mar.	+7·8	−48·5	−12·6	+8·6	+12·8	−67·1	+10·5	−8·2	−14·3	+20·9	−48·8	+19·7	−32·9	+19·0
Apr.	−9·0	−42·4	−25·7	+22·9	−1·7	−64·2	+10·3	−31·0	+12·7	+22·3	−52·6	+30·5	−46·0	+17·9
	w	e	E	W	w	E	W	E	e	w	E	W	E	W
	L	E	L	E	L	Av	E	L	L	Av	L	E	Av	

Components towards the east are positive.

E, W signify an increasing easterly or westerly component from February to March and e, w signify decreasing easterly or westerly components.

L, E or Av show whether the spring reversal at 30 mb over Scotland was early, late or average.

Kac[8] has shown that in the stratosphere there are considerable differences in the global circulation patterns depending on whether the flow is easterly or westerly in the equatorial zone. He suggests that the way in which the rearrangement of the high-latitude stratospheric circulation takes place depends on the type of circulation pattern prevailing in the tropics and that the different ways in which redistribution of air masses vary in association with the fluctuations in the equatorial stratosphere lead to differences in the zonal and meridional circulation indices in the stratosphere in higher latitudes. It does seem to be the case that if the phase of the equatorial quasi-biennial oscillation in the 30-mb zonal wind component is such that in the spring there is an increasing westerly (or decreasing easterly) component, then there is a marked tendency for the change-over to stratospheric summer easterlies over Scotland to occur early. The converse is also true and a decreasing westerly (or increasing easterly) in the spring at 30 mb over the equator usually appears to be associated with a later-than-usual reversal to easterly at 30 mb over Scotland. The outstanding exception is 1966 when the phase of the equatorial quasi-biennial oscillation at 30 mb was unquestionably decreasing easterly but the change-over to summer easterlies at 30 mb over Scotland was certainly not early. In 1963, 1967 and 1970 the change-over occurred very close to the average date and, as mentioned earlier, these years are difficult to classify as either 'early' or 'late'.

On the evidence for the years 1958–70 it might have been expected that the spring reversal would have occurred early in 1971 as the equatorial winds showed an increasing westerly component. However, Figure 2 shows that this did not happen and it is clear that the curve for 1971 bears little resemblance to those for the other years. The 30-mb pentad mean zonal wind components were comparatively light for most of the period and exceeded 20 kt in only four pentads. From mid-March to late May the winds were very light indeed — sometimes easterly and sometimes westerly. In some respects it might be argued that the 1971 final warming was early if considered on a hemispheric scale. In the second half of March there was a very marked warming (of about 30 degC) over the Russian Arctic and there was a high centre near the North Pole. There was also a warming over the Canadian Arctic but it was noticeable that the temperatures did not quite reach summer values in April. The events leading up to the break-down of the stratospheric vortex and the final warming in 1971 were certainly most unusual and no doubt papers will appear describing in detail the synoptic and dynamical events which took place.

The 1971 spring reversal and possible effects of volcanic dust. At this point it is tempting to speculate whether the unusual course of events in the stratosphere might have been influenced by an event which occurred in the previous year. In September 1970 there was a volcanic eruption at Jan Mayen (71°N 8°W) and it has been suggested by Lamb and Parker[9] that the dust cloud from this eruption was probably located above the 10-mb (30 km) level. Their method of locating the height of the dust cloud by examining gradient winds is very subjective and consequently some doubt remains as to the height reached by the dust in the days immediately following the eruption. If their estimate is correct then volcanic dust could have been present in the high-latitude upper stratosphere during the early months of 1971.

When Mount Agung, Bali (8°S 115°E), erupted in 1963 meteorologists were provided with very definite evidence and measurements concerning the dust cloud[10,11] and it was established that the presence of the dust had a very noticeable effect on the stratospheric temperatures.[12,13] Sparrow[14] has suggested that the observed rise in temperature may have been contributed to by a change in the phase of the quasi-biennial oscillation associated with the solar minimum or, on the other hand, that the dust may have been responsible for the observed changes in the behaviour of the oscillation. As the dust from this eruption reached 20 km it is reasonable to assume that temperatures near that level (i.e. 50 mb) would be higher owing to increased absorption of solar radiation. In fact the 50-mb monthly mean temperatures at Ascension Island (07°58'S 14°24'W) for September 1963 (the annual maximum) and for March 1964 (the annual minimum) were both warmer than usual and were both extreme values. The average rise in 50-mb monthly mean temperatures from the minimum (January–March) to the maximum (June–September) is 5·8 degC but in 1963 the rise amounted to 14·2 degC and much of this anomaly was almost certainly due to the presence of dust from the Bali eruption. In the case of the Jan Mayen eruption there was no sampling of the dust by aircraft and there is much less evidence regarding the height and extent of the dust cloud. However, if the dust did rise to 10 mb as suggested by Lamb and Parker then it is possible that its presence had an effect on stratospheric temperatures.

In the absence of any direct measurement of the height, composition and extent of the dust it is not possible confidently to associate any observed temperature anomalies in the stratosphere with the presence of the dust from Jan Mayen as was done following the Bali eruption. However, in assembling the relevant facts it should be remembered that the dust from Jan Mayen was ejected into the stratosphere at 71°N and that the area north of this represents only about 3 per cent of the earth's surface. Mean meridional motions in the stratosphere are very small indeed but it is known that at these latitudes, in winter in particular, there are eddy motions capable of transporting stratospheric particles over wide bands of latitude. Consequently, whilst some of the dust would be transported into lower latitudes some would probably be carried polewards and remain in the circulation around the vortex. Any volcanic dust in the high-latitude stratosphere during the winter months would also, of course, be subjected to some very pronounced vertical motions associated with 'sudden warmings'; it is known that one such warming took place in late December 1970 / early January 1971. If the dust did not reach levels above 30 mb in the days immediately after the eruption then particles in the lower stratosphere could well be carried to higher levels in such a warming. Nevertheless, in spite of the uncertainties concerning some of the statements made, it may well be possible that a relatively small quantity of dust injected into the high-latitude stratosphere is capable of having a significant effect on stratospheric temperatures in high latitudes.

The effect on the 30-mb temperatures in high latitudes (below the level of the top of the dust veil) could be to reduce the temperature as a result of increased absorption of solar radiation at the higher levels. As mentioned earlier, the stratospheric temperatures over the Canadian Arctic did show a warming in March but the values recorded were some 5 degC below the summer values to be expected after a warming. During the first few months

of the year the high-latitude temperature patterns at 30 mb are subject to wide variations both within a particular month and from one year to another but by May the monthly mean chart always shows a fairly typical summer pattern and so comparison of different years is easier then. It is of interest to note that at two stations in the Canadian Arctic (see Table IV) the monthly mean temperatures in May, June and July 1971 were well below the 10-year (1960–69) average.

TABLE IV—30-mb TEMPERATURES AT ALERT (82°30′N 62°20′W) AND EUREKA (80°00′N 85°56′W)

Station	Month	T_m	σT	δT	
		degrees Celsius			
Alert	May	−42·3	2·2	−3·2	equal to previous extreme in 1957
	June	−40·0	0·9	−2·4	extreme
	July	−39·8	0·6	−1·2	equal to previous extreme in 1955
Eureka	May	−42·5	2·2	−3·6	equal to previous extreme in 1955
	June	−39·9	1·0	−2·2	coldest apart from extreme of −42·7 in 1955
	July	−39·9	0·5	−1·1	coldest apart from extreme of −41·8 in 1955

T_m is monthly average for 1960–69. σT is standard deviation of the monthly means for the period 1960–69. δT is the departure of the monthly mean for 1971 from the 1960–69 average.

In most cases the negative anomalies in 1971 were extremes or equal to previous extremes but, as indicated in the table, if a previous monthly mean anomaly equalled or exceeded the 1971 value then it occurred in the early years of the record when the hours of ascent were different (in June 1957 there was a change from 03 and 15 GMT to 00 and 12 GMT). From 1960 the records at both stations are completely homogeneous and all the 1971 anomalies quoted in Table IV are cold extremes for that 11-year period. It is perhaps more significant that the 30-mb monthly mean temperature charts for May, June and July for the years since 1964 suggest that this anomalous cold was not confined to the Canadian Arctic. In May and June 1971 the highest temperatures in the warm area near the pole were lower than in most of the other years for which charts are available and in July 1971 the area enclosed by the −40°C isotherm appears to be appreciably smaller than in the other years.

Obviously this evidence is somewhat circumstantial, and there are some who will reject it, but it is worth bearing in mind that the presence of volcanic dust might have influenced the final warming and the stratospheric wind reversal in the spring of 1971 and also that it may have contributed to the three months of below-normal 30-mb temperatures in high latitudes from May to July 1971. It may even be that but for the presence of the dust the final warming would have taken place much earlier and this would add support to the idea that an increasing westerly phase of the quasi-biennial oscillation at 30 mb is associated with an early spring reversal of stratospheric winds over Scotland. Unfortunately it is unlikely that any direct measurements of the dust cloud will become available to prove or disprove this suggestion but it does seem to be more than coincidental that arguments can be advanced which suggest that the dust reached levels above 30 mb, that the mid-stratospheric temperatures over the Arctic in May, June and July 1971 should be colder than usual and also that the onset of stratospheric easterlies at 30 mb over Scotland should have taken place in what appears to have been a very unusual way.

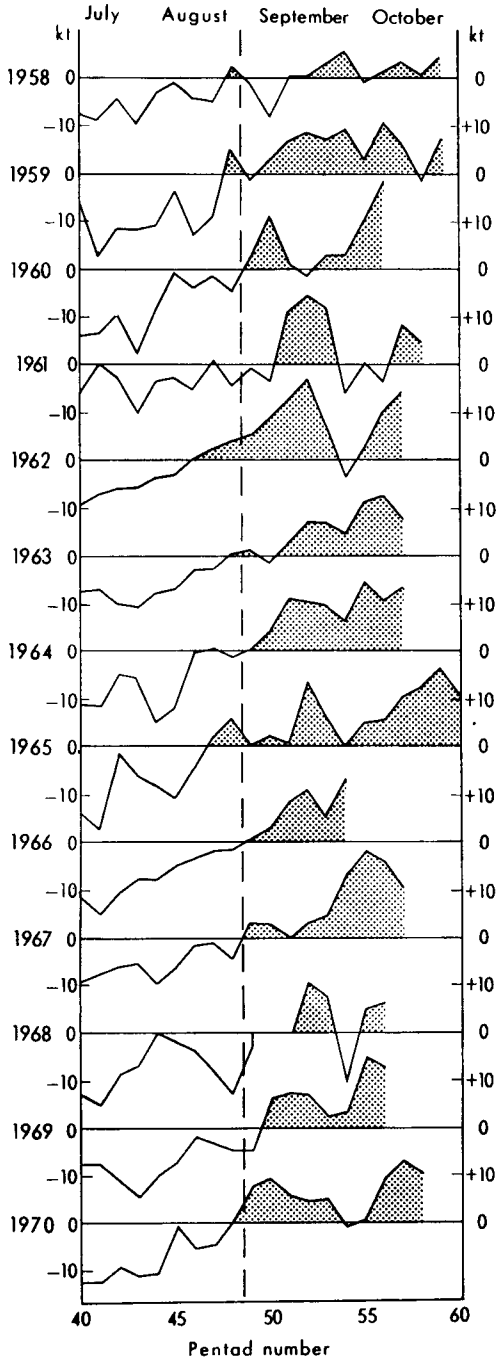


FIGURE 3—PENTAD MEAN ZONAL WIND COMPONENTS AT 30 mb OVER SCOTLAND FOR JULY TO OCTOBER FOR EACH OF THE YEARS 1958–70

Components towards the east are positive and stippled. The average time of the change-over to westerly is shown by the pecked line.

The autumn reversal. The average 30-mb pentad zonal wind components in Figure 1 show that over Scotland the summer easterlies are replaced by westerlies around late August or early September. Although there is some year-to-year variation in the time at which this autumn change-over takes place it can be seen from Figure 3 that it is a much more regular event than the spring reversal. Perhaps it could be said that the westerlies were established early in both 1962 and 1965, and it may or may not be significant that in 1961 and 1968 there were brief periods when easterlies were re-established in late September. However, in most years the change-over takes place within a short period near the average time of late August and, perhaps because of this more regular behaviour, the autumn reversal has so far attracted less interest than the spring reversal. The behaviour of the polar-night stratospheric vortex in autumn does, apparently, provide the Japanese long-range forecasters with an indicator for the following winter.[15] As more data become available, further study of the autumn reversal may reveal interesting stratospheric/tropospheric relationships about which little is known at present.

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551.515.1

A STUDY OF RAPID CYCLONIC DEVELOPMENT OVER THE CENTRAL MEDITERRANEAN IN SEPTEMBER 1969

By L. DENT and D. C. MASON

Summary. An account is given of the development of a disastrous late summer storm with gale-force winds over the central Mediterranean. The case study is used to illustrate the part played by several dynamical factors in cyclogenesis.

Introduction. The seasonally settled weather over the central Mediterranean, which normally breaks down in October, was brought to an abrupt end on 23 September 1969 by the sudden development of a depression and gale-force winds. Following a day and a night of prolonged heavy rain (Figure 1) at Malta the wind veered sharply to north-easterly and increased to gale force, producing conditions known locally as a gregale. Heavy seas were soon whipped up by the storm which caused considerable damage to shipping around the island, particularly to small craft moored in the many

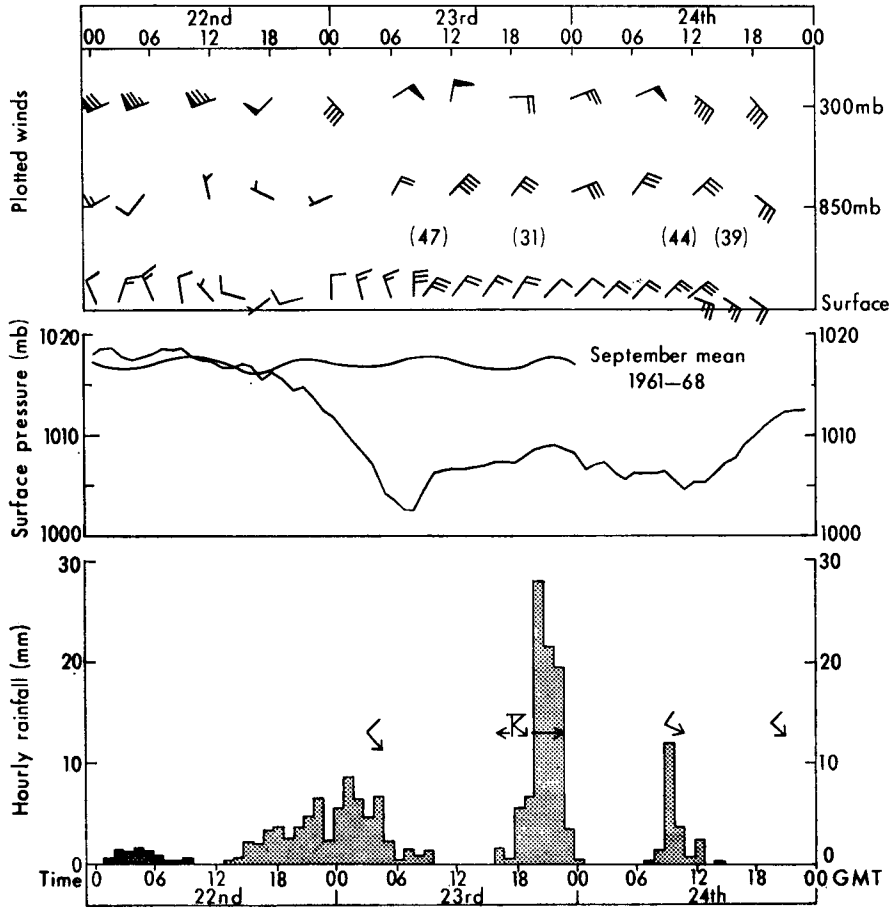

FIGURE 1—CHANGES IN WIND, PRESSURE AND RAINFALL AT LUQA ON 22–24 SEPTEMBER 1969

International plotting symbols are used. Figures in brackets in top diagram are maximum surface gusts.

creeks facing north-east. As the wind veered, the 22 000-ton tanker *Angel Gabriel* was driven on to rocks off St Thomas's Point, at 08 GMT on the 23rd, and broke in two with the loss of one crew member. The remainder of the crew were brought safely ashore in a joint civil and military rescue operation.

Heavy rain fell over Malta between 22 and 25 September when 194·7 mm were recorded at Luqa, of which 154 mm fell in the 36 hours after 12 GMT on the 22nd (Figure 1). Taken together, 22 and 23 September 1969 were the two wettest consecutive days in any month at Luqa since records began in 1946.

The evolution of this storm was an extremely complex process, as will be described later, but the authors' conclusions are that it formed quite suddenly to the east or south-east of Malta in the early hours of 23 September. It remained slow moving during the 23rd and began to move westwards on the 24th, crossing south-westwards into southern Tunisia on the 25th. The widespread devastation and loss of life from flooding which then occurred in Tunisia and Algeria has been described by Winstanley.[1]

Synoptic evolution. Two of the major contributing factors which led to the development of this remarkable storm were the south-eastward movement from Sardinia of a deep low in the upper layers of the troposphere, which passed to the south of Malta, and the movement from Libya to the Gulf of Sidra of a mobile, desert depression in the lower atmospheric layers. Other important factors were the non-adiabatic heat supply from the sea surface and latent-heat releases during heavy rain.

Associated with the upper low was a strong field of vorticity advection, which would be accompanied by ascending motion, and which advanced ahead of the centre. Simultaneously the desert depression, moving east-north-east, was instrumental in maintaining a thermal ridge and warm air advection field over the Gulf of Sidra and the Ionian Sea, and would also be accompanied by ascending motion where the warm advection was a maximum.[2]

The evolution of these synoptic features is shown in Figures 2–5, from which it will be noted that the shaded area of vorticity advection began to overtake the warm air advection field soon after 12 GMT on the 22nd. By 00 GMT on the 23rd there was an appreciable overlap of the two advection fields to the east and south-east of Malta. On the surface chart for 00 GMT on the 23rd (not shown) a cold front separated cool maritime north-west winds over Tripolitania from warmer desert air over Cyrenaica and extended northwards over the Ionian Sea to Sicily. This front had moved south-east across Libya during the previous 24 hours but had remained almost stationary near Sicily. A broad isobaric trough and light winds covered the Ionian Sea and Malta.

The difficulty at this stage of the analysis is the absence of observations to the south-east of Malta, and for this reason it is not possible to specify precisely where the depression developed, but it seems that a new separate circulation formed in the lower layers of the atmosphere between 00 and 03 GMT somewhere to the east or south-east of Malta. Three-dimensional analysis tends to support this supposition which is also consistent with observations of pressure and wind at Malta (Figure 1) and over Sicily on intermediate charts.

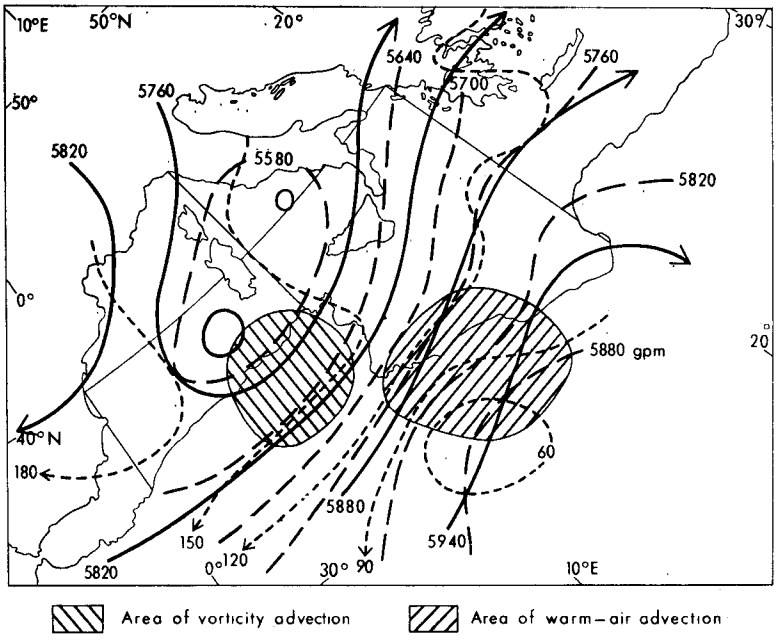

FIGURE 2—CONTOURS AND THICKNESS AT 00 GMT ON 22 SEPTEMBER 1969

– – – 1000-mb contours ——— 500-mb contours

— — 500–1000-mb thickness

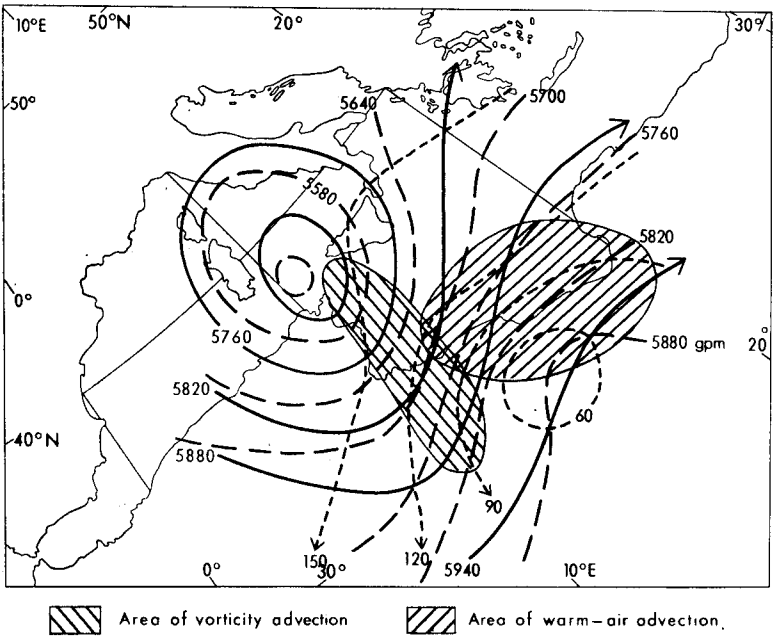

FIGURE 3—CONTOURS AND THICKNESS AT 12 GMT ON 22 SEPTEMBER 1969

– – – 1000-mb contours ——— 500-mb contours

— — 500–1000-mb thickness

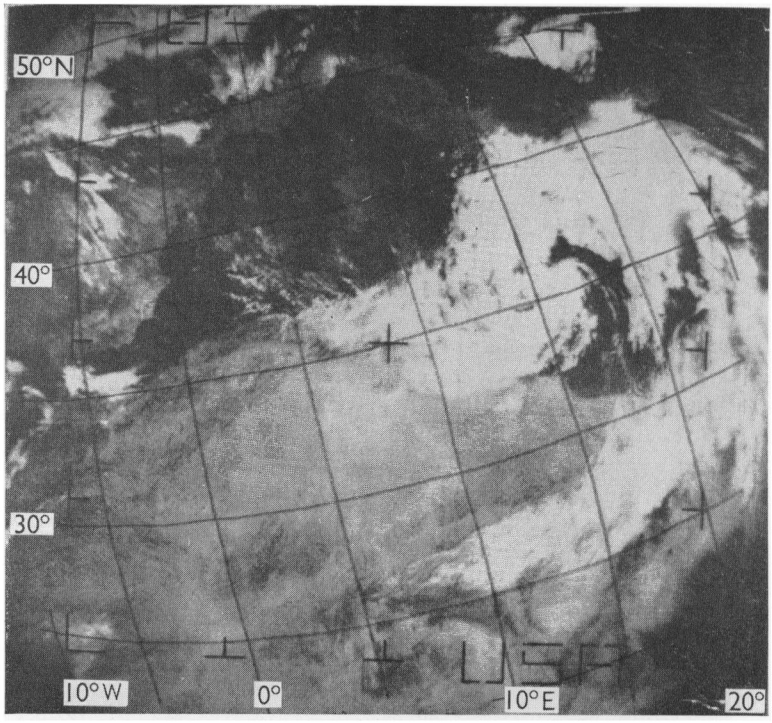

PLATE I—ESSA 8 SATELLITE PICTURE FOR 09 GMT ON 23 SEPTEMBER 1969

See page 82.

PLATE II—THE METEOROLOGICAL OFFICE COLLEGE AT SHINFIELD PARK, WHICH WAS OPENED IN OCTOBER 1971

(a) Classroom

PLATE II—*continued*

(b) Library

To face page 81

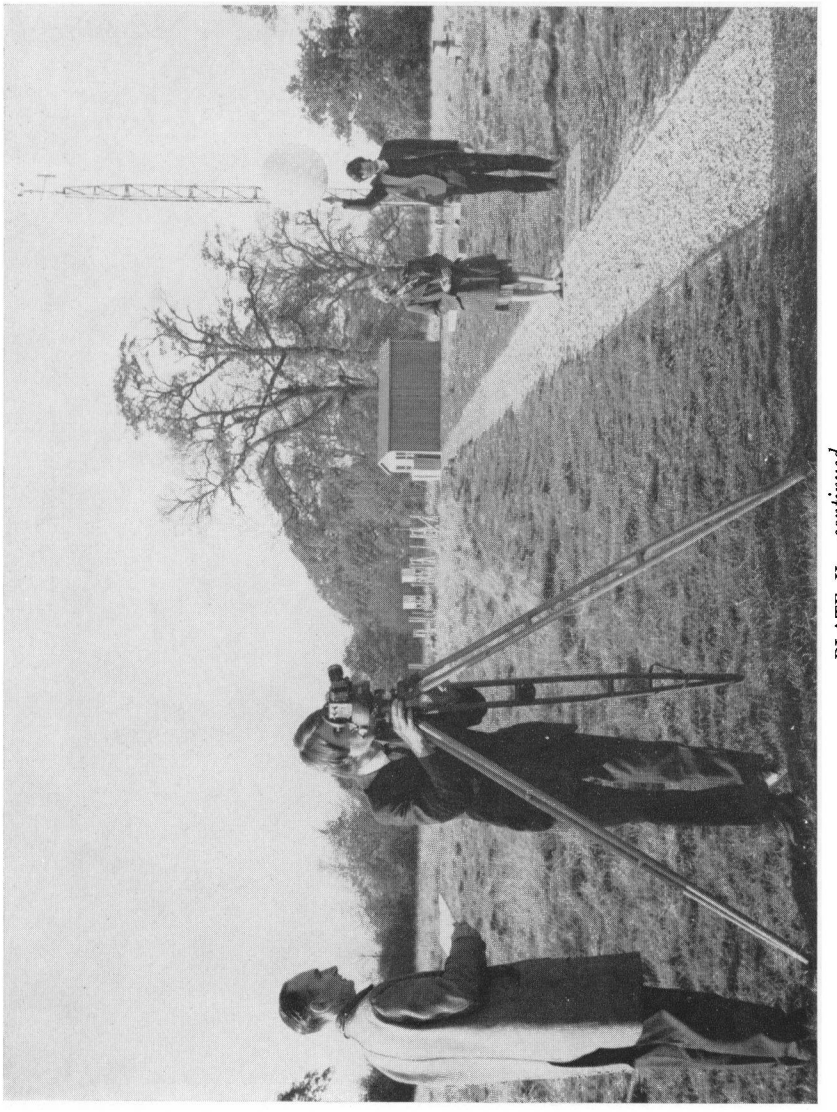

PLATE II—*continued*

(c) Observation area with enclosure in background

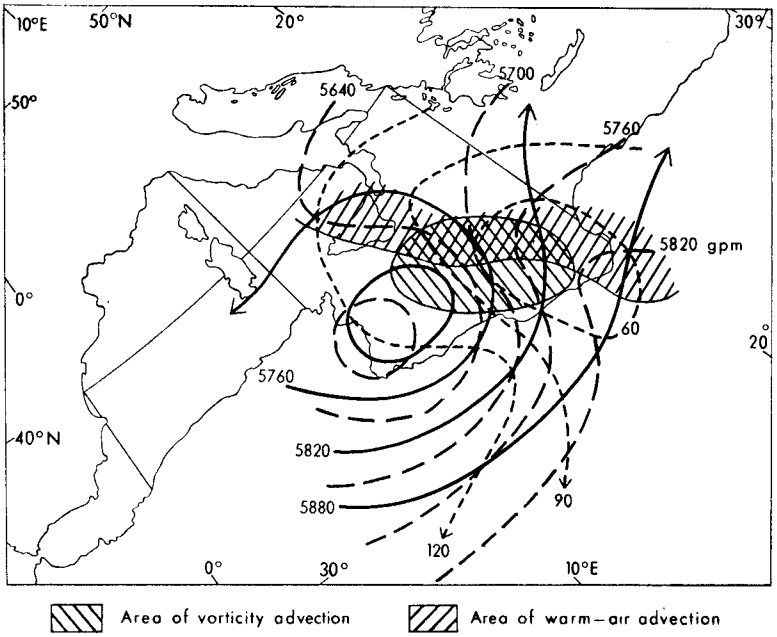

FIGURE 4—CONTOURS AND THICKNESS AT 00 GMT ON 23 SEPTEMBER 1969

– – – 1000-mb contours ——— 500-mb contours

— — 500–1000-mb thickness

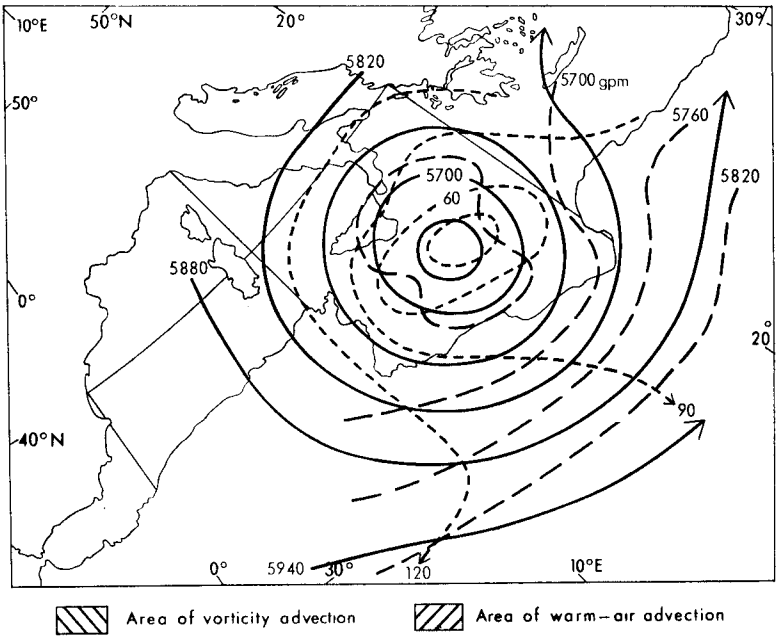

FIGURE 5—CONTOURS AND THICKNESS AT 12 GMT ON 23 SEPTEMBER 1969

– – – 1000-mb contours ——— 500-mb contours

— — 500–1000-mb thickness

In the event, on the 03 GMT chart for 23 September a deep depression appeared over the central Mediterranean to the east of Malta (Figure 6). The desert depression then moved away across Cyrenaica and filled. The ESSA 8 satellite picture for 09 GMT on 23 September (Plate I) shows the vortex to the east of Malta with an extensive mass of cloud extending into Tunisia, and the frontal band of cloud trailing south-westwards across Cyrenaica. The new centre quickly became concentric with the upper low, and deepening ceased. Considerable convective activity remained however to give further heavy rainfall, including over 80 mm in 5 hours at Malta late on the 23rd, and subsequently to devastate a large part of Tunisia and Algeria.

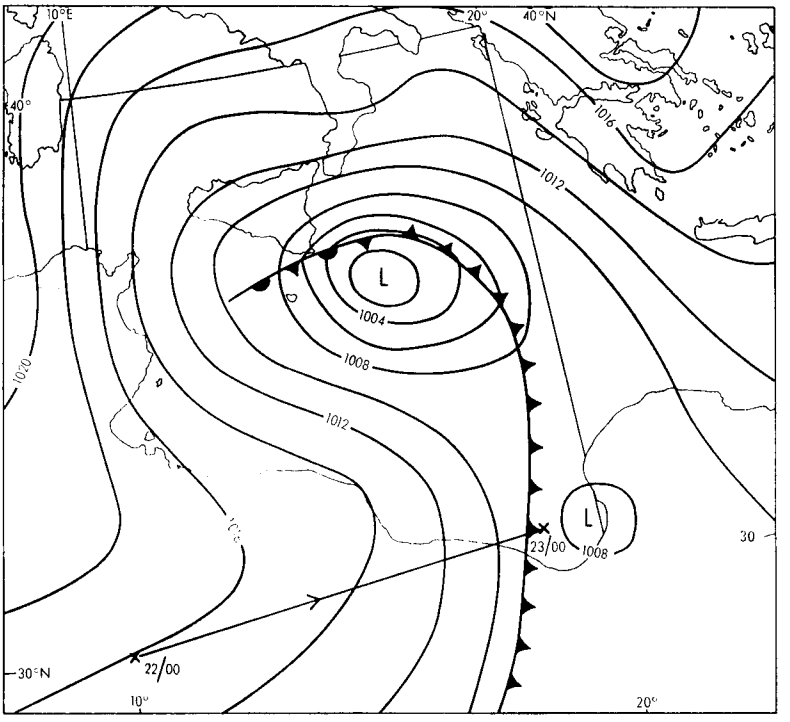

FIGURE 6—SURFACE CHART AT 03 GMT ON 23 SEPTEMBER 1969
Arrow shows 24-hour movement of desert low.

Dynamical aspects. Whilst describing the synoptic evolution it is instructive to refer to the dynamical factors which are responsible for changes in vorticity at sea level. Petterssen[2] has derived an equation as follows :

$$\frac{\mathrm{d}}{\mathrm{d}t} Q_{10} = -\mathbf{V}_5 \cdot \nabla Q_5 - \frac{R}{f}\nabla^2\left[-\frac{g}{R}(\mathbf{V}_{10} \cdot \nabla h_{TT}) + S + H\right] \quad \ldots (1)$$

where S and H are meaned over the layer 1000–500 mb and

$$S = \text{the static stability term, } \omega(\Gamma_a - \Gamma) \log \frac{1000}{500},$$

$$H = \text{the non-adiabatic heating term, } \frac{1}{c_p}\frac{\mathrm{d}W}{\mathrm{d}t} \log \frac{1000}{500},$$

V is the wind velocity on an isobaric surface, Q is absolute vorticity and h_{TT} is the 1000–500-mb thickness field. ∇, ∇^2, are operators denoting respectively the gradient and Laplacian of a function on the isobaric surfaces. Subscripts 5 and 10 refer to 500 mb and 1000 mb respectively.

Equation (1) is similar to equation (3) in a recent paper by Morris[3] but omits terms representing vorticity advection at 1000 mb and vertical advection of vorticity, and twisting terms. For a full explanation the reader is referred to Chapter 16 of Petterssen,[2] in particular to his equation 16.2.11 from which the immense complexity of development is evident and at sea level emerges as an imbalance between the vorticity advection at the level of non-divergence and the Laplacian of the thermal components. Thus briefly equation (1) implies that sea-level cyclogenesis is favoured by: advection of cyclonic vorticity at 500 mb, a maximum of warm air advection, an unstable environment and the release of latent and sensible heat.

During 21 and 22 September (see Figures 2 and 3) the desert depression moved east-north-eastwards across north Africa and by 12 GMT on the 22nd had passed to the south of Wheelus Field in Libya and was approaching the Gulf of Sidra, with a prominent area of warm air advection extending northwards from the low centre towards Malta. The prominence of the thermal advection is demonstrated on the hodograph for Wheelus Field in Figure 7. During the same period the upper tropospheric cold vortex had moved south-east from Spain and by 12 GMT on the 22nd the 500-mb vortex was south-east of Sardinia with a trough to the south. The probable area of cyclonic vorticity advection is depicted in Figure 3.

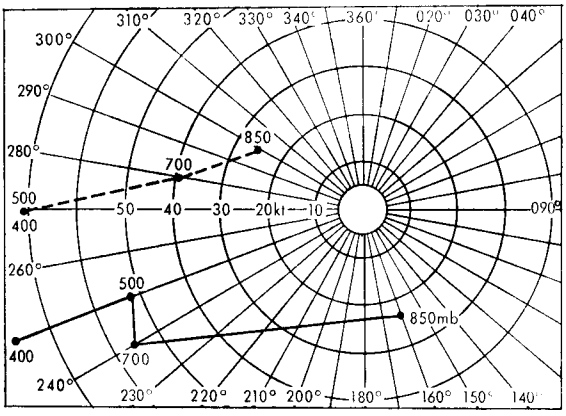

FIGURE 7—HODOGRAPH ANALYSIS FOR WHEELUS FIELD IN SEPTEMBER 1969
——— 12 GMT on 22nd - - - 00 GMT on 23rd

It will be seen that the independent movement of the upper trough and the Libyan depression would lead to an increase in the area of overlapping of the warm air advection field by the cyclonic advection aloft. In accordance with equation (1) this implies an increase of cyclonic vorticity at sea level. This overlapping of upper and lower systems would also enhance the amount of upward motion.[3] Accordingly the air in the middle and lower troposphere might be expected to cool adiabatically so that by 00 GMT on the 23rd (Figure 4) it is likely that a near moist adiabatic lapse rate was present in the environmental air over a limited region just east or south-east of Malta.

Figure 8 depicts the upper air sounding for Wheelus Field at 12 GMT on 22 September and for Malta at 00 GMT on the 23rd. The Wheelus sounding is representative of the air within the thermal ridge (Libyan cyclonic system) and it is important to note the potential instability shown by the decrease of wet-bulb temperature upwards to 700 mb. The Malta sounding was colder and more moist than Wheelus and also unstable to sea temperatures of 23°C. If it be assumed that the Malta sounding above 600 mb was representative of the upper cold trough, the overlapping of the warm advection field by the upper cyclonic vorticity advection field at 00 GMT on 23 September was synonymous with the overrunning of the Wheelus lower air mass by the Malta upper air mass. In view of the enhanced upward motion within this composite environment it would not take long to remove the dry layer between 800 and 600 mb through adiabatic cooling and also perhaps by evaporation of rain falling from upper levels. Hence the potential instability of the environment would be released with copious supplies of sensible and latent heat within a relatively small area east and south-east of Malta. Thus it may be seen that all the terms in equation (1) were probably combining to produce sea-level cyclogenesis at 00 GMT on the 23rd.

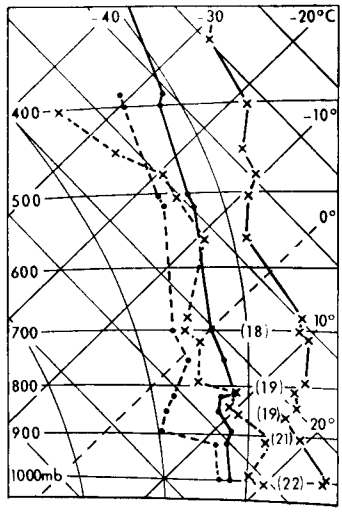

FIGURE 8—UPPER AIR ASCENTS FOR WHEELUS FIELD AND MALTA IN SEPTEMBER 1969

Wheelus Field, 12 GMT on 22nd
x——x Temperature
x- - -x Dew-point

Malta, 00 GMT on 23rd
· —— · Temperature
· - - - · Dew-point

The evidence of surface pressure changes supports the theoretical expectations, with the accelerated fall of pressure first observed at Malta at 00 GMT on 23 September and subsequently in Sicily as the area of development moved towards Malta and Sicily, and culminated in the rapid formation of a cyclonic storm centre to the east or south-east of Malta.

Figure 5 shows the synoptic situation at 12 GMT on the 23rd. It will be seen that 'development' had also occurred at 500 mb which probably reflects the role of the feedback terms which were neglected in equation (1).

Acknowledgement. The authors wish to thank Mr R. M. Morris for his help in writing the section on dynamical aspects.

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551.558.21

TILTED OR ASYMMETRIC MOUNTAIN WAVES

By T. A. M. BRADBURY

Summary. Observations from gliders over Scotland show that there is sometimes a marked degree of upwind tilt to the wave front in mountainous areas. On such occasions the changes in the horizontal and vertical components of wind are not symmetrical through the wave pattern. Where the wave appears tilted the band of ascending air is relatively narrow and the horizontal component of the wind is often relatively weak. In contrast, over and particularly downstream of the wave crest the horizontal component of the wind can be unexpectedly strong. The vertical component on the lee side is then likely to be weaker than on the upwind side. The width of the zone of descending air is however wider than the zone of ascending air.

Introduction. For some years glider pilots who have flown in lee waves over Scotland have reported certain interesting features of the airflow which may be summarized as follows :

(a) The area of lift on the upwind side of the wave often appears to slope forward. The slope is sometimes so great that at high levels the wave appears to overlap the low cloud marking the next upstream wave.
(b) The horizontal wind encountered during the climb is sometimes much less than expected. Some reports suggest that the occasions of light wind occur when the vertical currents are particularly strong. This decrease of wind is occasionally so marked that the glider is able to circle for a brief period instead of flying almost directly into wind to remain on the forward side of the wave. (In normal circumstances a glider which attempts to circle in wave lift is quickly carried into the region of descending air.)
(c) The band of lift on the upstream side of the wave appears narrow, while the region of sinking air on the lee side is unusually broad.

These observations suggest that the streamlines of the airflow through the waves are not simple oscillations but part of a more complex pattern producing a tilted wave front.

There have been a number of earlier observations of tilted wave fronts and the first published diagram showing some degree of tilt appeared in a paper by Küttner.[1] Tilted waves also appear in mathematical studies by Lyra,[2] Queney,[3] Corby and Sawyer,[4] and Scorer.[5] Pao[6] computed a number of flow patterns for a stably stratified inviscid fluid and published diagrams of these patterns at various Richardson numbers. His pattern when $(Ri)=0{\cdot}833$ shows a number of features which appear to fit the observations of Scottish

* See also the correction on p. 96.

glider pilots. A simplified version of this flow pattern is given in Figure 1, with pecked lines showing the tilt of wave crests, and troughs added to emphasize the point. It may be noted that the streamlines show that the horizontal component decreases at middle levels on the upwind side of the wave, but there is also a region of much stronger flow over the crest and for a considerable distance downstream from it.

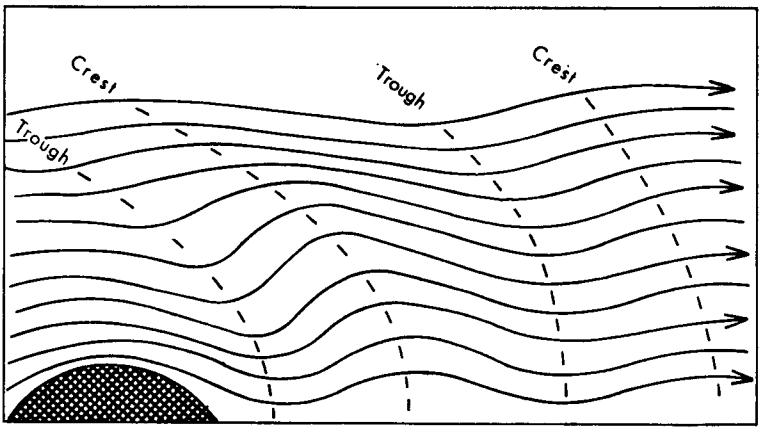

FIGURE 1—TILTED WAVE FLOW PATTERN (after Pao[6])

Glider observations over Scotland. In March 1971 an opportunity arose to make notes during a period of lee-wave flow over Scotland. A number of gliders were then visiting Portmoak, the site of the Scottish Gliding Union (56°12′N 03°20′W). On 9 and 10 March numerous flights were made to heights between 18 000 and 25 000 ft.* On the 9th a cold front passed southwards through the area and the associated increase of cloud made it impossible to keep an accurate visual plot of position. On the 10th there were sufficient areas of clear air to allow pilots to establish their positions for much of the time. In the account which follows certain important positions were established from subsequent study of a series of photographs which showed ground details identifiable on large-scale maps.

The general pattern of the waves was deduced from radio reports amplified by subsequent verbal and written descriptions. These reports were not sufficient in themselves. They formed the framework within which the more detailed personal notes made in flight could be worked up, with some confidence that the data from a single glider were not unrepresentative.

Rates of climb for this glider were calculated from stop-watch and altimeter readings and also from the barograph trace. The rate of sink of the glider was calculated from the published performance curves after correcting the indicated airspeed for changes of density. It has been assumed that the true vertical velocity of the air can be determined by adding the calculated sinking speed in still air to the achieved rate of climb. This is only practicable when the airspeed has been kept constant for the period of measurement. However,

* Conversion factors to metric units are : 1 foot = 0·3048 m; 1 knot ≈ 0·5 m/s.

in the very smooth conditions often encountered during a wave climb it is frequently possible to trim the glider to fly almost 'hands off' and then the airspeed can be kept within two knots of a constant value. Furthermore, since control movements are then at a minimum the actual sinking speed is likely to be close to that established on test. (Any control motion increases drag and hence alters the sinking speed.)

Instrumental errors were unlikely to be great enough to influence results: the airspeed indicator has been recalibrated at annual intervals and the readings were within official tolerance before and after the flight; the barograph was calibrated by an official observer and heights were taken from the curve prepared by him; the altimeter, when compared with the barograph, showed a small but consistent under-reading at high levels.

The flight on 10 March consisted of two main climbs together with a number of exploratory searches. The first climb covered the period 1036 to 1130 GMT when the nearest wave system was used to gain height for more extensive exploration. At this stage there were four other gliders, all in radio contact, using the same wave. It was therefore possible to establish the main area of rising air with some confidence. The lowest part of the wave was marked by a line of cloud just to the lee of the Ochils. Since this cloud remained almost stationary throughout the climb it is probably true to assume that the wave too was almost stationary. During the climb the band of lift was found to be tilted forward, as shown in Figure 2, which also shows the underlying cross-section of the Ochils north-west of Kinross.

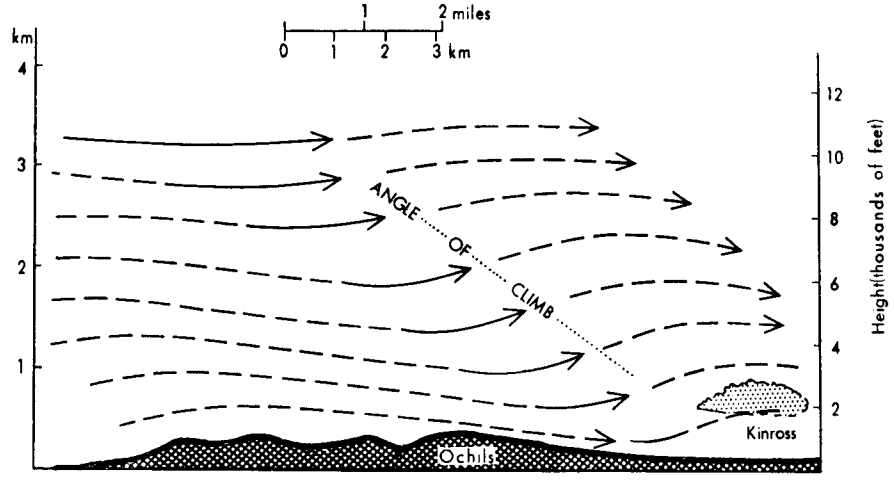

FIGURE 2—WAVE FLOW PATTERN OVER THE OCHILS NORTH-WEST OF KINROSS ON THE MORNING OF 10 MARCH 1971

Not only did the zone of rising air tilt forward with height but it was also found that the air over the leading edge of the cloud, 3000 ft above the cloud top, was descending. Had the wave front been vertical, one would have expected to find a small upward component above the leading edge of such a cloud.

From interchange of information between a number of gliders flying over an area stretching from near Leuchars in the north-east to Dollar in the south-west, it appeared that the wave flow was still rather weak and pilots

were unable at that time to climb much above 12 000 ft. A change occurred after 12 GMT when lenticular clouds began to form at many levels as moister air ahead of a frontal wave began to spread over from the north-west. Figure 3 shows the surface chart with the 1000–500-mb thickness lines superimposed. Until that time there had been little visible indication of the location of lee waves but during the afternoon the positions were clearly marked by some very extensive lenticular clouds.

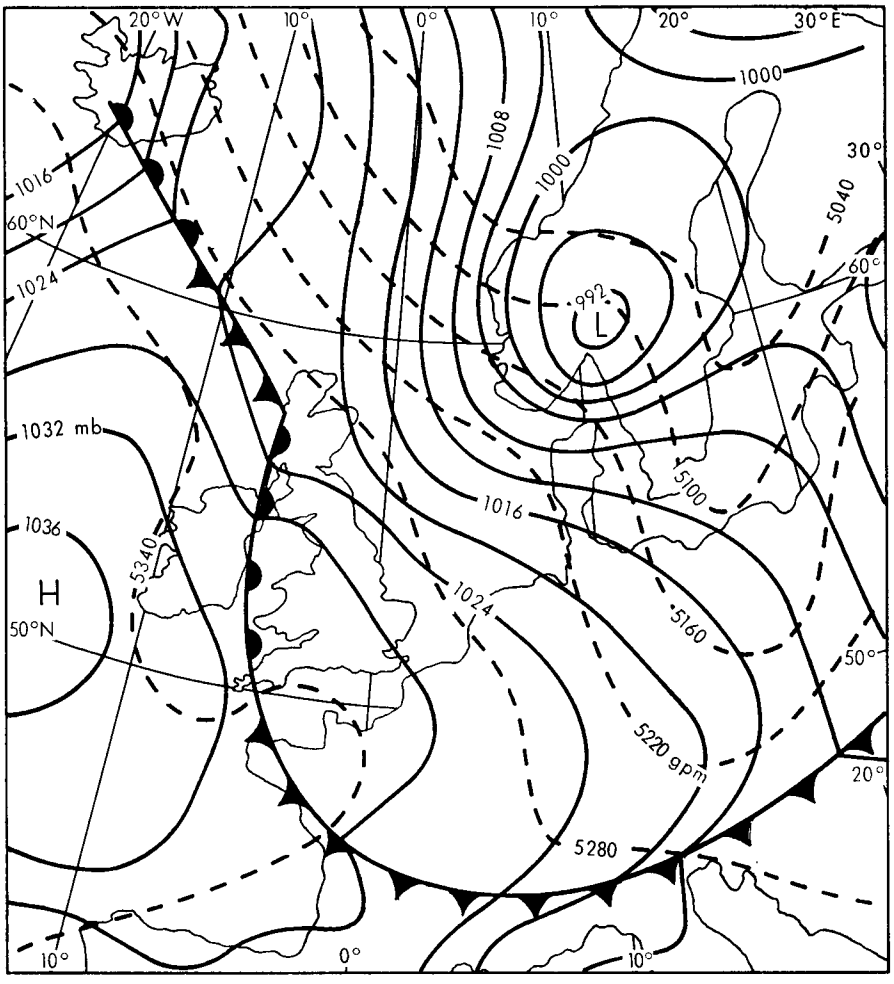

FIGURE 3—SURFACE AND 1000–500-mb THICKNESS CHART AT 12 GMT ON 10 MARCH 1971

At 13 GMT it was decided to head for Crieff where these clouds appeared most marked. The route traversed a wide area of descending air over the lower section of the Ochil range south-east of Perth. However, although the area was broad the vertical component of the airflow was relatively weak. The upstream wave was marked by a band of stratocumulus and once again the wave front tilted forward so that the region of upcurrents was not encountered until the glider was several hundred yards ahead of the cloud

below. In contrast to the broad area of descending air the rising air occupied a very narrow band, but the upward velocity was approximately twice the downward velocity observed on the lee side of the wave crest.

The main climb was made in the area near Crieff during the period 1336 to 1500 GMT, starting at 7000 ft and ending at 23 000 ft. During this climb it was necessary to advance approximately six miles (≈9·5 km) upwind to remain in front of the wave crest. Figure 4 shows the cloud structure and apparent tilt of the wave front. In both cases where this tilt could be plotted the slope had a gradient of about 1:2. For most of the time the true airspeed was 47–55 kt, not all of which was flown directly into wind. Since the glider was actually making some progress upwind it is unlikely that the mean horizontal component exceeded 50 kt and it may have been appreciably less.

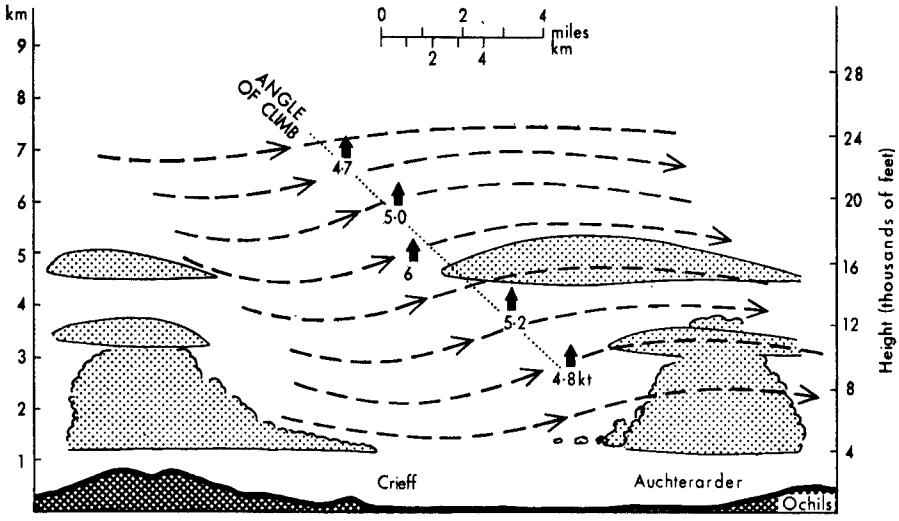

FIGURE 4—WAVE FRONT AND CLOUD STRUCTURE NEAR CRIEFF ON THE AFTERNOON OF 10 MARCH 1971

Vertical velocities on the climb are shown by short arrows with speeds below.

From the top of the climb near Crieff it was possible to fly cross-wind at a true airspeed of 90 kt without experiencing excessive drift, but quite a different wind field was encountered near Loch Lomond. The glider was then at nearly 20 000 ft and an attempt was made to fly into wind to reach the next wave. Speed was increased to within a few knots of the maximum permitted. At one stage the true airspeed reached 136 kt but even so no appreciable forward progress was made during a descent of 7000 ft and the attempt was abandoned in order to remain clear of cloud. It appeared that there was an unusually strong band of winds on the lee side of the next wave between the levels of 19 500 and 12 500 ft. It was necessary to return to the original wave where the wind velocity returned to normal. Although cloud cover made it impossible to estimate a drift angle the plot of the return track showed no further sign of unusual wind strength. Certainly the wind velocity along the upwind side of this wave front, which extended from near Loch Lomond (approximately 56°04′N 04°30′W) to Leuchars (56°22′N 02°52′W), did not exceed 40 kt at levels between 10 000 and 12 000 ft.

Further evidence of localized strong winds. Figure 1 shows that with this type of flow, unusually strong winds may be experienced at low levels, as well as higher up on the lee side of waves. Table I shows the upper winds of the midday soundings from Stornoway and Shanwell. It can be seen that whereas the Stornoway wind profile is fairly typical of conditions for wave flow, the Shanwell wind profile is distorted by a narrow band of anomalously strong winds at the 850-mb level. If this wind is taken to be representative of the undisturbed wind field, it implies a thermal wind in the 850–500-mb layer reciprocal to the thickness lines, and also suggests that lee waves would be unlikely. Since there is no reason to doubt the accuracy of the Shanwell report it may be presumed that the balloon was penetrating one of the layers of anomalously strong winds as it passed the 850-mb level.

TABLE 1—UPPER WINDS FOR 12 GMT 10 MARCH 1971 AT SHANWELL AND STORNOWAY

Shanwell			Stornoway		
Pressure level	Wind Direction	Speed	Pressure level	Wind Direction	Speed
mb	*deg*	*kt*	*mb*	*deg*	*kt*
200	320	43	200	320	52
272	295	46			
300	295	45	300	325	57
			312	325	61
400	305	46	400	330	57
440	310	45	411	335	56
500	325	45	500	325	47
600	330	40	600	310	38
			677	305	32
700	315	41	700	310	31
800	325	48	800	310	33
850	325	53	850	310	30
876	315	45			
914	295	32	918	320	30
1021	220	14	1022	330	14

Similar anomalous winds, also implying a reversal of the expected thermal (or partial thermal) wind, are occasionally reported over Norway and it may be that the smoothing applied to wind measurements does not always mask genuine singularities caused by lee waves.

Conclusions. One of the flow patterns calculated by Pao[6] for an inviscid fluid seems also to occur in the free atmosphere when lee waves develop in a mountainous area. Generalized reports from a number of glider pilots, combined with a more detailed study of a single occasion, appear to confirm the existence of tilted asymmetric waves. There is so far no evidence to show how commonly such waves occur, nor is it known if the same effect can be found in the waves further downstream when the air passes out to sea.

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WORLD METEOROLOGICAL ORGANIZATION COMMISSION FOR AGRICULTURAL METEOROLOGY FIFTH SESSION – GENEVA, OCTOBER 1971

By C. V. SMITH

In some ways, this fifth meeting of the Commission for Agricultural Meteorology (CAgM) represented a watershed, or even a climax as far as the United Kingdom was concerned. It is perhaps unlikely that either of the U.K. delegates, Dr Gloyne or C. V. Smith, will in fact be able to be present at future meetings of the Commission, whilst the man so closely associated with the development of the Commission over the past 20 years, and who has done so much to lead the Commission to maturity, both in the scientific and organizational sense, chose to bring his close association with the Commission to an end at this time — Mr L. P. Smith, President for the past 9 years, left Geneva with no formal duties within the Commission. Many delegates from the 50 countries represented were slightly incredulous; I think they may rest assured that his passionate interest in the problems that the Commission sets out to resolve will not keep his pen from paper for long.

The delegates came with divergent interests and difficulties. In a few countries the problem in recent years has been one of the disposal of agricultural surpluses; the fortunes of agricultural meteorology are inevitably linked with those of agriculture and in these countries they are in decline. Established patterns of capital intensive farming in such regions are only marginally affected by the introduction of alternative crops; the expertise of the individual farmer is already high and governmental intervention is perhaps more social than economic, interested neither in simple production nor yet in productivity. Projections of the future world demand for food would suggest that this lack of interest can only represent a short-term difficulty for agricultural meteorology in the countries now carrying a food surplus.

At the other extreme there were those who were concerned primarily with the development and expansion of national agricultural output, through an extensive rather than an intensive approach. The infra-structure necessary for intensive production is perhaps inadequate at the present time and the emphasis brought by delegates from such countries was on land-use planning, on agro-climatic mapping, on zoning for new plant and animal introductions, and on training in agrometeorology. This demand, in developing countries, for agrometeorological advice at governmental level on the feasibility and advisability of investment projects, must dominate the subject during the next few years. The reasons for the demand for such advice are quite pragmatic; they stem from difficulties and unanticipated side effects found in existing expansion projects, where early agrometeorological consultation was inadequate.

This need to influence the thinking of those concerned with the allocation of resources, and with decision making at all levels of management, was reflected in the discussions of the Commission.

A Working Group was established to revise the *Guide to agricultural Meteorological practices* and among the agreed new chapter headings are:

(6) Agricultural forecasts (meteorology-based).

(8) Weather risk assessment for agricultural planning decisions.

A U.K. recommendation aimed at generating credibility for agrometeorology at the highest level, through illustrative case studies employing conventional middle-level management techniques, found expression in the establishment of a rapporteur on this topic (though perhaps not quite with the terms of reference which a U.K. rapporteur would have written). The importance the Commission was persuaded to attach to this subject resulted in this rapporteur being specifically entered into the President's Advisory Working Group and charged primarily to keep a watching brief on the economic aspects of agrometeorology.

It was also agreeable to find that another U.K. recommendation on the need to initiate further work on the meteorological aspects of aerobiology was taken up and expanded and resulted finally in a new Working Group.

Among the papers called for by the previous meeting in Manila (CAgM IV — 1967) and approved for publication in the World Meteorological Organization *Technical Note* series are :

Weather and animal diseases by L. P. Smith.

Some problems of intensive animal houses by C. V. Smith.

Protection of plants against adverse weather by G. W. Hurst and R. P. Rumney.

Publication of U.K. work on the Colorado beetle was held up pending the inclusion of information to be made available from Eastern Europe and the European Plant Protection Organization.

A further U.K. report on minimum temperatures brought to light so many more questions than the original terms of reference anticipated, that three rapporteurs and international experiments have been instituted.

Current U.K. commitments are fewer than in the past. The U.K. is to provide the rapporteur on mulches, whilst Dr Gloyne is to chair a Working Group on soil deterioration and erosion; help will probably also be given to an Animal Disease Working Group.

Soil deterioration is but one example of the factors leading to a falling off in production, an area of work for the agrometeorologist emphasized by the President in his report to the Commission. A concern for the environment may be topical but is not new to agricultural meteorologists who have long since learned that they must identify problems from the bottom up and not from the top down, if their work is to be effective. Erosion may represent an irreversible process and if one may anticipate a likely quotation at CAgM VI — 'It is already later than you think'.

Other areas of work for the Commission were summarized by the President under the headings of :

Techniques to improve food production.

Meteorological factors involved in problems of plant and animal physiology.

Meteorological factors involved in field operations.

Meteorology as an input to strategic decision making.

Micrometeorological research and soil/plant/animal/atmosphere interactions.

Past and current reports, future rapporteurs and working groups are to be found under all these headings.

It would be wrong to close any report on the meeting without reference to the emphasis that the Commission gave to collaboration with FAO,

UNESCO, UNDP, ISB, ISSS, IGU, IUGG.* Surveys of climatic resources of large parts of the globe, experimental projects involving several countries in studies on the introduction of new plant varieties, training through the establishment of seminars — none of these past and present activities would have been possible without the combined initiative and efforts of CAgM and these other bodies. Such collaboration is not by any means purely organizational. For example, coffee leaf rust, a fungal disease, currently constitutes a significant threat to many countries in southern and central America and the Caribbean. A further spread on any large scale could have disastrous economic consequences for countries where coffee is the main cash crop. UNDP and FAO, as a matter of urgency, are preparing plans to reduce the impact of the disease. CAgM has set up a Working Group to assist. It is just possible that these few men could point the way to save the economic livelihood of a subcontinent. Conscience dictates that all possible international assistance should be provided. Self interest in a shrinking world leads to the same conclusion. In the end agrometeorology is concerned with people, and with results as well as ideas.

REVIEWS

Thermal interaction of the atmosphere and the hydrosphere in the Arctic, by Yu. P. Doronin. 245 mm × 173 mm, pp. viii + 244, *illus.* (translated from the Russian by Israel Program for Scientific Translations, Jerusalem), Keter Press Ltd, 15 Provost Road, London NW3 4ST, 1970. Price: £8.

The author's Institute has been concerned for many years with the interaction between the atmosphere and the underlying water/ice layer in the Arctic. Perhaps its best-known data-gathering expeditions have been those on drifting ice stations and results from these have been used extensively in the book. The text is divided into eight main sections, beginning with a chapter on turbulent exchanges of momentum, heat and water vapour between surface and atmosphere. Chapter 2 discusses the surface radiation balance and is followed by a section dealing with vertical heat exchange in the sea. Most of the remainder of the book uses these ideas to develop treatments of ice accretion and the annual freezing/thawing cycle but there is also a section on the effect of surface exchanges on the tropospheric temperature and pressure fields and a final short chapter on the possibility of artificially modifying the Arctic climate.

The middle part of the book discusses topics most closely allied to the author's own researches and is written with some authority but other sections are less convincing. Chapter 1 is especially confusing and the formulae for vertical turbulent transfer developed here by using the turbulent kinetic energy equation without its divergence term have little credibility. Most of this chapter is in any case irrelevant since in the remainder of the book Doronin uses conventional bulk-aerodynamic formulae for representing vertical exchanges at the surface. In Chapter 3 the discussion of vertical mixing in a stably stratified sea ignores completely the layered structure

* i.e. Food and Agriculture Organization; United Nations Educational, Scientific and Cultural Organization; United Nations Development Programme; International Society for Biometeorology; International Society for Soil Science; International Geographical Union; International Union for Geodesy and Geophysics.

observed in these conditions in the absence of wave mixing and includes an uncritical reference to the well-known Kattegat observations of turbulent mixing with an apparent Richardson number around 10.

The book will probably have only limited appeal to anyone not actively involved in the field, as it goes into considerable mathematical detail. Additionally, its value as a definitive text is reduced considerably by the author's frequent presentation of conflicting results from different sources without guidance on which are the more plausible.

The volume may perhaps be of most value as a source of references to predominantly Russian work, but unfortunately, although published in its original form in 1969, it lists very few references beyond 1966 and must be considered already somewhat out of date. Printing is in a cramped format and symbols in the formulae are far too small for easy reading.

N. THOMPSON

Interpretation of observational data from meteorological satellites, by K. Ya. Kondrat'ev, E. P. Borisenkov and A. A. Morozkin. 245 mm × 173 mm, pp. v + 370, *illus.* (translated from the Russian by Israel Program for Scientific translations, Jerusalem), Keter Press Ltd, 15 Provost Road, London NW3 4ST, 1970. Price: £5·50.

This monograph, written at a relatively high technical level, was first published in the U.S.S.R. in 1966. At that time it must have fulfilled its purpose admirably — 'a first attempt to summarize the latest advancements in applied satellite meteorology'. The translation, published in 1970, comes too late to do real justice to the book. So much has happened in the world of meteorological satellite technology, as indeed in most other meteorological activities, that one cannot avoid the criticism that much of the book is now sadly out of date. Nevertheless, there is of course much useful information and comment to be derived from it.

The title of the book is an excellent one; an up-to-date version of a book of this kind is necessary in any large meteorological organization. At the time of its original publication, it made available to its readers in the U.S.S.R. a vast amount of information from sources in the U.S.A. A puzzling thought is why the authors have made so little reference to Soviet meteorological satellites. We are told in the foreword :

> 'The discussion is restricted to data from American meteorological satellites, since most experience has been gained by interpreting these data. The authors have benefited much from the WMO Seminar on the interpretation and use of meteorological satellite data held in Tokyo during 1964. Different problems of applied satellite meteorology were discussed in great detail during the Seminar in which one of the present authors participated. Two interesting and fully illustrated volumes of data and methodically well-designed exercises on nephanalysis were prepared by members of the staff of the U.S. Weather Bureau for practical work at the Seminar. Part of this material was used by the authors in preparing this book.'

This international basis adds value to the book in a broad sense but makes the translation of less importance, for surely a great part of the value of a

translation from U.S.S.R. sources lies in the knowledge to be gained from an independent approach to common problems.

The book is divided most logically into four chapters, followed by a good selection of satellite photographs. The chapters are :

(1) The potentialities of satellite-borne equipment for meteorological research.
(2) The use of radiation data obtained with meteorological satellites.
(3) The processing of meteorological satellite data.
(4) The practical use of television and infra-red pictures obtained from meteorological satellites.

The first chapter has a large historical content including details of the U.S. satellite programme, starting with VANGUARD II and EXPLORER VII and ending with NIMBUS I. As might be expected, much of this has little application to present needs. The best part is a section entitled 'Global meteorological observation system'. The authors' opinion is that a global meteorological system should be based on the following component elements :

(a) The totality of conventional observation methods (ground-based meteorological, aerological, radiometric, ship- and aircraft-instrument observations, etc.).
(b) Meteorological satellites.
(c) A system of meteorological sounding balloons (and radiosondes), ocean buoys, and ground-based automatic weather stations operated jointly with satellites that carry out collection and transmission of the received data.
(d) Manned orbiting space laboratories.
(e) Lunar meteorological stations for Earth observations.

It is interesting to quote the comments on the last two items. Manned orbiting space laboratories provide the following advantages :

'(1) the possibility of deliberate choice of the object to be investigated,
(2) supervision (monitoring) of the complex instrumentation,
(3) the testing of new instruments (and the checking of calibration which is difficult to carry out automatically),
(4) visual observations.'

With regard to item (e) :

'A lunar meteorological observatory (LMO) for Earth observations . . . can play an important role in the visual or instrumental tracking of large-scale atmospheric processes. The absence of atmosphere on the Moon makes it possible to carry out on the lunar surface measurements of the solar constant; data of such measurements are instrumental for solving the problem of the Sun's influence on weather. Of considerable interest are also measurements of the Earth surface. This same installation could also be used to measure components of the radiation budget on the lunar surface and the radiation temperature of the latter. Since the Moon always turns the same face toward the Earth it suffices to set up on its surface a single station for the observation of the entire Earth surface and atmosphere as the Earth rotates about its axis. Of particular meteorological interest will be the transmission of infra-red pictures of the Earth which will permanently supply data on the distribution of cloud cover, temperature, and height of cloud tops, as well as information on the temperature of the underlying surface in cloud-free regions for the whole hemisphere.'

Chapter 2 begins by outlining the radiation balance of the Earth surface–atmosphere system and the spatial structure of the outgoing-radiation field and then proceeds to more practical aspects such as the analysis of infra-red cloud pictures, radiation forecasting and the determination of surface temperature, cloud height and moisture in the troposphere. The recent breakthrough achieved with the use of satellite infra-red spectrometer data is of course not mentioned.

Chapter 3 is concerned wholly with what may be called the housekeeping aspects of satellite data interpretation. These comprise the geographical correlation of television pictures and the elimination of distortion factors, the geographical orientation of automatic picture transmission data, the interpretation of nephanalysis data and the processing of outgoing-radiation data.

Then follows the most useful part of the book, Chapter 4, which deals with those aspects of satellite data likely to be of most value to meteorologists at outstations. This is the part that has suffered least from the ravages of time. The detailed treatment of the interpretation of satellite pictures is supplemented by numerous illustrations and examples. This section can be recommended.

As a whole, the book provides plenty of evidence of the qualities that are connoted by the term 'scholarship'. Extensive references in each chapter suggest that more than usual care has been taken. It is unfortunate that this translation, apparently an admirable one, will not prove exciting reading for meteorologists who are moving with the times.

T. H. KIRK

HONOUR

The following award to a member of the Meteorological Office was announced in the New Year's Honours List, 1972 :

O.B.E.

J. Harding, Assistant Director (Agricultural Meteorology and Hydrometeorology).

OBITUARY

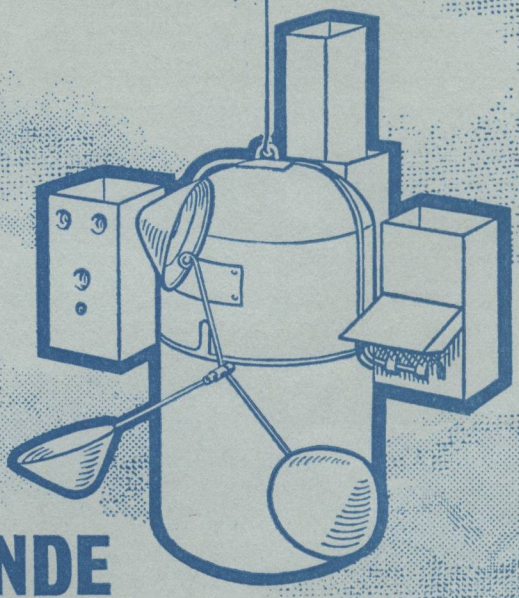
Mr J. Durward, C.M.G., died on 2 December 1971 on the eve of his 79th birthday. He was Deputy Director (Services) when he retired in 1954 and was one of the best-known meteorologists in the international field. He was closely associated with civil aviation at a time of rapid development and he played a major part in the establishment of upper air networks and in the organization of ocean weather stations on the North Atlantic. Our deepest sympathy is extended to his widow and sons.

P. J. MEADE

CORRECTION

Meteorological Magazine, January 1971, p. 15, line 15 to read :
H = the non-adiabatic heating term . . .

For accurate upper atmosphere recordings—



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Printed in England by The Bourne Press, Bournemouth, Hants

and published by

HER MAJESTY'S STATIONERY OFFICE

21*p* monthly **Annual subcription £2.82 including postage**

Dd. 500918 K16 3/72 SBN 11 400197 9